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The University of Minnesota
Agricultural Experiment Station

Respiration of Shelled Corn

By C. H. Bailey
Division of Agricultural Biochemistry

UNIVERSITY FARM, ST, PAUL

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INTRODUCTION

Shelled indian corn, or maize, the caryopsis or grain of *Zea mays,* presents an unusual hazard in marketing. Considerable quantities of this cereal are damaged each season as the result of heating when shipped or stored in bulk. About fifteen years ago the European buyers of corn reported that millions of bushels of American corn were discharged at continental ports in a damaged condition, and as a result of their representations the United States Department of Agriculture began a study of the problem. Duvel (1909)[1] reports observations made on bulk corn stored in a Baltimore elevator, the temperature of which reached 133° F. about 8 inches below the surface when left undisturbed from February 17 and 18 to April 27, 1909. From the bottom to a point about two-thirds of the distance to the top of the bin, corn of practically the same character as the surface layer did not change temperature appreciably, but remained cool and sound. Heating corn near the surface of the grain in the bin was so badly damaged that many of the germs were badly discolored, and the average germination was only 10.3 per cent. Corn from the lower 45 feet of the bin gave an average germination of 80.8 per cent at the beginning of the experiment, 71.4 per cent when drawn from the bin, and 81.4 per cent after being handled and dried.

Shanahan, Boerner, and Leighty (1910) state that on examining thirty-four cargoes of corn on arrival at eight of the principal European ports, an average of 12.1 per cent of the corn on board was in a heating or hot condition. Part of this damage could probably, in certain instances, have been obviated by better methods of storage, or by more rapid transit.

Duvel and Duval (1911) stored corn in the hopper scale of a Baltimore elevator on January 5, 1910, and on May 2 the surface layer reached a temperature of 138° F. The same authors (1913) report several series of experiments with corn while in cars in transit. In the first series, beginning April 14, 1910, one car of corn with an initial temperature of 58° F. reached a temperature of 142° F. on May 2, 1910. Corn with a higher moisture content did not change temperature in box cars between December 24, 1910, and January 20,

[1] Bibliographic citations in parentheses refer to "Literature Cited," page 40.

1911, while in a third series of experiments between March 2 and March 29, 1911, one car changed temperature from 40.8° F. at the time of loading to 112° when unloaded. A fourth series loaded in cars May 11 and unloaded June 1, 1911, was affected much like the first, the temperature of the damp corn being 64.2° F. when loaded, and 129° when unloaded.

Boerner (1919) presents the detailed observations of numerous transoceanic corn shipments. Temperatures as high as 146-147° F. were observed in portions of certain cargoes at the time of arrival in Europe, and considerable percentages of many cargoes were badly damaged in consequence of heating in transit.

The investigations cited establish the fact that corn may heat and undergo serious damage when stored in elevator bins, or while in transit in cars or in holds of vessels. Increases in the volume of shelled corn handled in commerce have contributed to the difficulties of its safe transportation and storage. Combined with this has been an apparent tendency on the part of producers to grow large-eared, late-maturing varieties of corn which contain comparatively high percentages of moisture at the time they are shelled for fall marketing. The Office of Grain Standardization (1913) of the United States Department of Agriculture published diagrams indicating that the average moisture content of corn received at Baltimore, Chicago, and New Orleans ranged between about 18.5 and 20.5 per cent during November, December, January, February, and March of the four crop years from November, 1909, to March, 1913. The shelled corn marketed later in these several seasons contained appreciably less moisture, the average being about 13 per cent or less by August. The reason for the regular seasonal variation in the moisture content of commercial corn is found in the more or less continuous drying which the corn undergoes during the months following harvest, since even during the winter ear corn dries gradually if stored in well-ventilated cribs.

RELATION OF RESPIRATION TO HEATING OF GRAIN

It is generally agreed by physiologists that energy for many physiological processes and reactions is released in living cells in an exothermic reaction or succession of reactions known collectively as respiration. In normal or aerobic respiration, oxygen of the atmosphere diffuses or is otherwise conducted to the cells where respiration occurs, and is there involved in a process of oxidation of which water and carbon dioxid are the characteristic end-products. The carbon dioxid which is formed diffuses or is conducted from such cells to the atmosphere surrounding the organism. The quantity of carbon dioxid respired bears a fairly definite relation to the quantity of heat energy liberated, and can be converted into terms of calories of heat through the use of a simple factor. Anaerobic respiration, which occurs in the absence of atmospheric oxygen, presumably utilizes the oxygen of certain compounds which are present, in the production of completely oxidized end-products such as carbon dioxid, while at the same time partially oxidized and reduced compounds are produced which are of different character in the different species thus respiring. Enzyms are assumed to be in a measure responsible for the reactions involved in respiration, altho no one has succeeded in simulating such reactions outside the living cell through the use of enzym preparations. Certain physiologists include respiration as one of the criteria of "life," but there is also evidence that respiration occurs in certain organisms which are "dead" as judged by ordinary standards. This fact is of significance in connection with the respiration of damaged corn kernels which are no longer viable.

Investigations of Langworthy and Milner (1913), and Gore (1914) with bananas, and of Hasselbring and Hawkins (1915) with sweet potatoes support the views of Borodin (1876), Maige and Nicolas (1910), and others that in normal plant tissues containing simple hexose sugars, such sugars are the principal substances oxidized. Palladin (1918) says "Regarding the cell as a factory, carbohydrates are the coal and the protoplasm is the machinery" (p. 208).

Germ or embryo cells are evidently the location of most of the respiration occuring in a typical grain. Burlakov (1897) found that 100 grams of soaked wheat grains respired at the rate of 15.2 milligrams of carbon dioxid per hour, while the same weight of embryos respired at the rate of 241.8 mgm. of carbon dioxid per hour. Karchevski (1901) reports a ratio of about 1 to 12 in the comparative rate of respiration of wheat kernels and the germs or embryos. Palladin calls attention (p. 209) to the general relation between rate of carbon dioxid elimination and the percentage of "indigestible" or "protoplasmic" proteins in various tissues. Such proteins are chiefly of the group known as nucleoproteins, and in the corn or wheat kernel are present largely in the germ. Such indirect evidence lends further support to the assumption that respiration in the endosperm cells of such grains is at a low level. Kolkwitz (1901) found that when he cut wheat kernels half way from end to end, the germ end respired three times as much carbon dioxid as the opposite end when equal weights of material were compared. Osterhout's (1917) observation that oxidation is more rapid in the nucleus than in the cytoplasm of living cells might also lead to the deduction that, since the cells of the germ have a larger proportion of nuclear material by weight than the large starchy parenchyma cells of the endosperm, respiration should proceed at a higher rate in the germ tissues.

There is reason for doubt, however, as to how much the various organisms such as bacteria and molds on the surface of the kernels contribute to the total carbon dioxid respired and heat energy released in bulk grain. Loew (1899) maintained that in the fermentation and heating of leaf tobacco the rise of temperature was due to the release of heat energy through the activity of the cellular oxidizing enzyms of the tobacco leaf tissues. He did not concede that microbial flora play any significant part in these heating processes, and opposed the bacterial-fermentation theory previously advanced by Suchsland (1891).

Nabokich (1903) sterilized beans with aqueous bromine (1 to 500) and corrosive sublimate (1 to 1000) solutions and then inoculated them with the washings from natural beans. The seeds so treated respired less carbon dioxid during the first day, but thereafter respired about one third more than the sterilized seeds which had not been inoculated. In a second series beans were sterilized and then inoculated with washings from a portion of the unsterilized seeds, with which their respiratory rate was then compared. In general the sterilized seeds behaved peculiarly, in that they respired more vigorously than the controls at the outset, but later failed to reach so high a rate. The disinfecting solutions apparently acted as narcotics in effecting an initial stimulation followed by a reduction in the respiratory rate. Because of this fact the data presented by Nabokich are somewhat difficult of interpretation, and suggest that the use of such disinfectants in respiration studies may give rise to abnormal conditions, and yield results of doubtful value. Moreover he was working with water-soaked seeds, while in commercial grain the moisture content is much below maximum imbibition, and the substratum to which the molds and bacteria are attached is not so well suited to active propagation and metabolism of those organisms as is soaked material.

Gore (1911) concluded that in self-heating, physiological processes are probably the first to operate, while Rahn (1910) states that the curve of the process of spontaneous heating of organic matter, including grain, would not in itself indicate whether the heat was produced by chemical or microbial causes. E. M. Bailey (1912) studied the ripening of bananas and indicates that bacterial activity is not responsible for the heat produced or for other changes occuring during the ripening of the fruit. The marked increase in liberation of carbon dioxide resulting from raising the temperature of wheat from 45° to 55° C., which was observed by Bailey and Gurjar (1918) suggests that possibly thermophylic bacteria were partly responsible for the relatively large quantity of carbon dioxid liberated at such high temperatures. Ordinarily the respiration of organs of higher plants is depressed on raising their temperature above 40° or 45° C.

In bulk grain the factor of significance, however, is the total quantity of heat energy released per unit of time, and since the reactions which give rise to carbon dioxid are exothermic, it is not of vital importance to determine whether the heat energy is released as the result of respiration within the tissues of the kernel, or in respiration or other exothermic reactions on the surface of the grain. In either event the heat energy becomes distributed throughout the bulk of grain and serves to raise its temperature if not immediately dissipated into the surrounding medium. Carbon dioxid liberated in respiration and related phenomena can be conveniently and accurately determined. In these studies of shelled corn, as in the previously published studies of stored wheat by Bailey and Gurjar (1918), the rate of respiration was determined and reported in terms of the quantity of carbon dioxid respired per unit of time and material. This method of study is convenient because of the ease and rapidity with which each sample can be examined, as well as the more exact control which can be effected in working with small quantities of grain.

It is recognized that a determination of the respiratory rate does not afford a simple means of computing the temperatures which the grain in question would attain under commercial conditions of storage. The writer has previously indicated (1917) that the actual change of temperature depends not alone upon the rate of respiration of the grain, but upon the size and shape of the bulk, the insulation afforded by the material of which the container or bin is constructed, the temperature of the surrounding medium (usually air), and the initial temperature of the grain itself. An equation by means of which the temperature change can be computed is accordingly complex, involving several variables, but such an equation has been presented and discussed by Hoffman (1918). Determinations of the rate of respiration are useful in comparing different lots of grain under uniform conditions of storage, however, thus affording a means for computing the relative quantity of heat evolved under the conditions imposed. This can not be done with large quantities of grain, since in such cases anything approaching an exact control of the physical conditions of the environment is manifestly unattainable.

METHOD OF STUDYING GRAIN RESPIRATION

In determining the rate of respiration the first step was to seal a suitable quantity of corn in a large calcium chloride tower. The weight of corn used depended upon the moisture content. When this was under 14 per cent it was customary to use from 500 to 800 grams of grain, while the weight used was reduced as the moisture content increased until only from 100 to 150 grams were employed when the moisture content was in excess of 17 per cent. The quantity of respired carbon dioxid could thus be kept within the limits of capacity of the absorption vessel. At the time of sealing the grain in the tower a representative sample was drawn for analysis. Air in the tower was drawn off and replaced by air freed from carbon dioxid, after which all joints were carefully sealed with paraffin. In all instances except when temperature was the variable (one series), the cylinders of grain were maintained at a temperature of 37.8° C. (100° F.) in an air thermostat. This temperature was maintained because the experience of the trade, as well as observations made in controlled experiments, indicates that at or slightly above 100° F. the condition known as "bin-burn" or "heat-damage" makes its appearance. The behavior of grain at this temperature is of particular interest, since it determines whether its temperature will continue to rise until serious damage results to the grain, or whether the heat energy released in bulk grain will be dissipated into the surrounding atmosphere as fast as produced in respiration. Acceleration of respiration with increasing moisture content was determined in one series incubated at 27.8° C., or 10 degrees lower than the temperature employed in all the other series. There was no significant difference in the response to increasing moisture content in the series at 27.8° C., the respiratory rate being a fairly constant fraction of the rates observed at the higher temperature.

The grain was allowed to respire about 96 hours before drawing off the carbon dioxid, because it appeared from preliminary studies that sufficient carbon dioxid to depress the respiratory rate did not appear in that time. Extending the period appreciably would, in the case of damp corn, result in a reduction of the rate of respiration. Shortening the period was not deemed advisable because (1) the quantity of carbon dioxid respired by dry grain would have been reduced to so small a quantity as to be difficult of accurate determination, and (2) the time required to heat the grain from its initial temperature (that of the laboratory atmosphere) to the temperature of the thermostat would have constituted too large a proportion of the total period of respiration, thus increasing the error from that cause. Since it was not always convenient to incubate for exactly 96 hours, the time that the towers were in the thermostat was noted, and the results were calculated uniformly to a 24-hour basis. Continuous removal of the respired carbon dioxid by aspiration during the entire incubation period was suggested, but proved unfeasible because such treatment altered the moisture content of the grain.

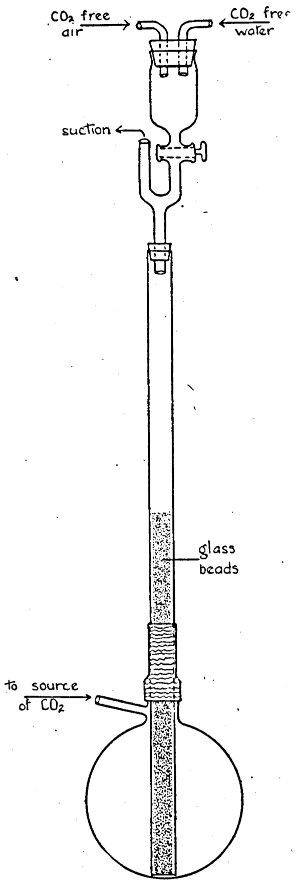

Figure 1. Modified Truog Absorption Tower

Immediately after the towers containing the corn were removed from the thermostat they were connected through an outlet tube to the absorption device. The latter was a tower similar to that described by Truog (1915), but slightly modified by using a round-bottomed distilling flask in place of a suction flask, and by providing a small reservoir for distilled water over the tower tube. The round-bottomed distilling flask is of the style furnished with the Brown-Duvel moisture-testing apparatus, and is convenient for a number of reasons. The round bottom is of advantage because more of the alkaline solution that is used can be drawn up into the tower tube than is possible with the ordinary suction flask. The straight sides of the neck of the distilling flask make possible the selection of a tower tube which fits quite snugly within the neck, and is of so nearly the same external diameter as the latter that a tight joint can be produced by slipping a piece of gum "gooch tubing" over both neck and tube at the point where the latter emerges. Thick-walled distilling flasks of the style mentioned can be purchased which are sufficiently substantial to give excellent service. The complete absorption tower is illustrated in Figure 1.

In the tube of this tower was placed a measured volume of nearly saturated barium hydroxid solution, the volume used being varied somewhat, depending upon the quantity of carbon dioxid to be absorbed. With dry corn 20 cc. of the barium hydroxid solution was used, while with damp grain this was increased to 50 cc. The calcium chlorid towers in which the grain was contained were provided with inlet tubes at the top through which carbon-dioxide-free air could be admitted, while the air containing respired carbon dioxid was drawn off through a tubulure at the bottom and passed into the absorption tower containing the $Ba(OH)_2$ solution. Ten volumes of air were thus drawn down through the grain, completely sweeping out the carbon dioxid. When the carbon dioxid had been removed and absorbed, the residual $Ba(OH)^2$ in the absorption tower was determined by titration with standard HCl solution, and since the original charge of $Ba(OH)_2$ was known, a simple calculation gave the quantity converted into carbonate, which in turn could be computed in terms of carbon dioxid.

The Cain-Maxwell (1919) method for the determination of carbon dioxid was also employed in the later stages of these studies. The principle involved in this method is the measurement of the rise of electrolytic resistance of a solution of $Ba(OH)_2$ by its conversion into $BaCO_3$ as CO_2 is absorbed. A special combined conductivity cell and absorption vessel was devised by Cain and Maxwell which allows the ready and complete absorption of CO_2 in passing through the barium hydroxid solution and the measurement of the electrolytic resistance of the solution before and after the absorption of the carbon dioxid. Through the use of formulas or charts the change in resistance can be converted into terms of CO_2. The cell and absorption vessel are illustrated in Figure 2.

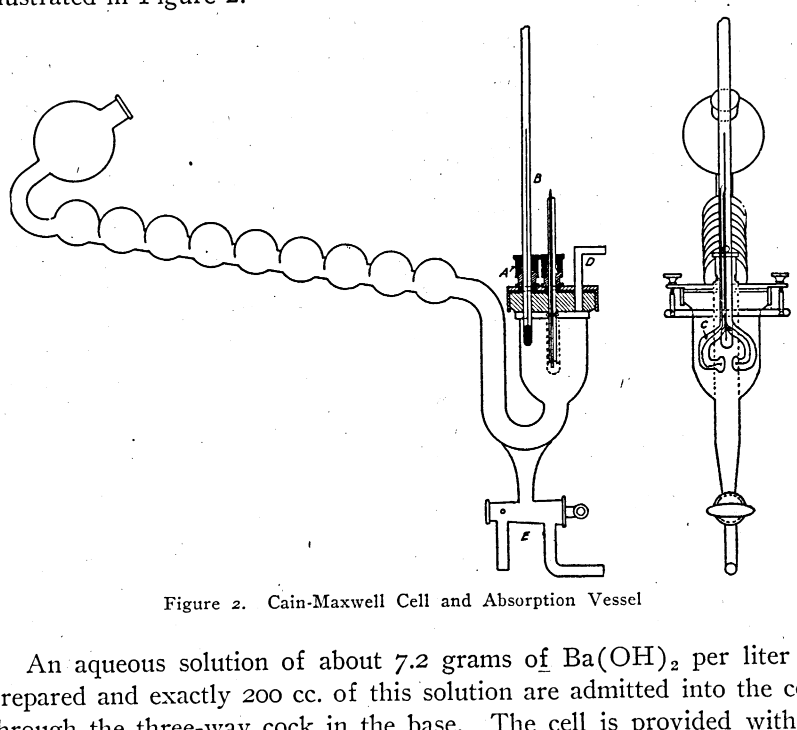

Figure 2. Cain-Maxwell Cell and Absorption Vessel

An aqueous solution of about 7.2 grams of $Ba(OH)_2$ per liter is prepared and exactly 200 cc. of this solution are admitted into the cell through the three-way cock in the base. The cell is provided with a graduation showing the height to which this quantity of solution rises.

The temperature of the solution in the cell is observed, and the electrolytic resistance is measured by means of the conventional Wheatstone bridge set-up, using a telephone receiver or a high-sensitivity, alternating-current galvanometer to detect the point of balance. A simplified resistance-measuring device is available which embraces a set of resistances connected to dials arranged in decades, and a galvanometer which is operated on the ordinary 110-volt, 60-cycle, alternating current. This device does away with telephones, high frequency generators, balanced inductances and capacities, and relieves the operator of the strain and consequent fatigue attendant upon the use of such instruments.

Mixtures of air and carbon dioxid are aspirated through the Cain-Maxwell cell and absorption vessel at a rate not to exceed from 300 to 400 cc. per minute. To determine at any time the quantity of carbon dioxid absorbed, the current of gases is shut off, the solution allowed to flow back into the cell, its temperature observed, and the electrolytic resistance measured as before. These data can then be converted into terms of carbon dioxid through the use of appropriate formulas or the nomograph prepared by Cain and Maxwell. This nomograph makes possible the application of the temperature correction in a simple manner. Since the nomograph as furnished with the cell has an arbitrary "carbon scale" rather than a scale in terms of carbon dioxid, the latter is calculated, each small unit representing 0.01 per cent on the carbon scale of the nomograph being equivalent to 0.733 milligrams of carbon dioxid.

Barium hydroxid solutions containing less than 5.5 grams of $Ba(OH)_2$ per liter of solution are not very efficient in absorbing carbon dioxid unless the gases are bubbled through it at a slow rate. It is therefore advisable to cease aspirating through a cell which has a cell constant of 0.715 when the resistance of its contents exceeds 110 ohms, this being the resistance at 25° C. which is equivalent to about a safe minimum concentration of $Ba(OH)_2$. If the initial concentration of $Ba(OH)_2$ is 7.2 grams per liter, the cell has a capacity for about 80 milligrams of carbon dioxid. A more concentrated solution of barium hydroxid could be employed where larger quantities of carbon dioxid must be absorbed at one operation, it being possible at least to double the capacity of the cell, altho at the expense of accuracy. The nomograph prepared by Cain and Maxwell must be expanded in order to accommodate it to the use of more concentrated solutions.

Certain advantages of this method over the titrimetric procedure are: (1) No standard volumetric solutions are required. (2) The quantity of carbon dioxid respired during any interval of time can be determined without disconnecting or tearing down the set-up, by momentarily shutting off the gas stream and measuring the electrolytic resistance of the solution. (3) Through the use of the simplified bridge and alternating current galvanometer, measurements can be made by a relatively inexperienced operator. The two outstanding objections which have been suggested are (1) the cost of the necessary equipment, and (2) its limited capacity for carbon dioxid. The latter is not a serious objection in many plant respiration studies.

DISTRIBUTION OF MOISTURE BETWEEN COB AND KERNELS

Earlier studies having established that the moisture content bears an important relation to respiration in stored grain, the moisture distribution in ear corn during the curing process is of some significance. A lot of Johnson County white dent corn, grown at the Maryland Agricultural Experiment Station in 1920, was employed in an experiment to determine the comparative rate of change in moisture content of cob and kernels while curing. This corn was cut and shocked about October 21, 1920, and the ears were removed from the stalks and husked on October 28. One portion of this husked corn was hung up in the heated laboratory, while another portion was stored in an unheated barn. Moisture content of the cob and kernels of these two portions on different dates is shown in Table I, the same data being presented graphically in Figure 3. These show that as the ear dries out, the cob, which has a materially higher initial moisture content than the kernels, loses moisture at a more rapid rate; in this experiment containing less moisture than the kernels when the latter had a moisture content below 14 per cent.

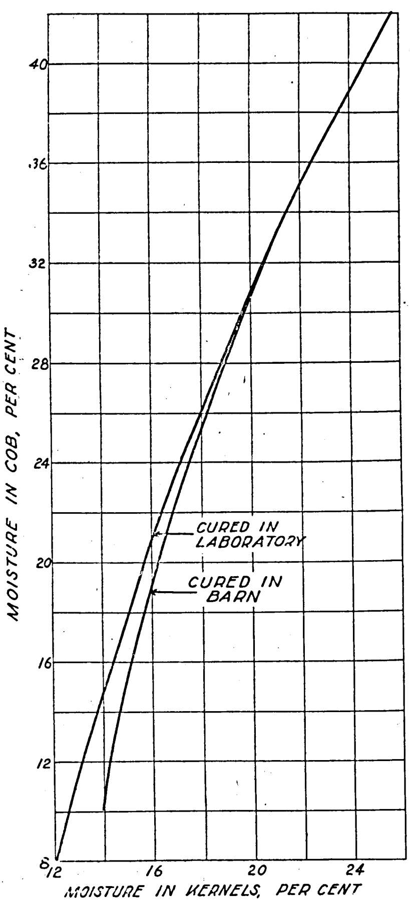

Figure 3. Percentage of Moisture in Cob and Kernels During Curing of Ear Corn

TABLE I

PERCENTAGES OF MOISTURE IN COB AND KERNELS OF EAR CORN AT DIFFERENT TIMES DURING CURING PROCESS

Date	Moisture content			
	Cured in laboratory		Cured in unheated barn	
	Cob	Kernels	Cob	Kernels
1920	Per cent	Per cent	Per cent	Per cent
Oct. 28*	42.02	25.77	42.02	25.77
Nov. 4	26.00	17.80	....	....
Nov. 12	13.78	14.41	32.07	20.69
Nov. 24	....	....	26.31	18.37
Nov. 29	8.06	12.05	....	....
Dec. 3	....	....	24.90	17.90
Dec. 24	....	....	22.79	17.21
1921				
Jan. 15	....	....	20.49	16.54
Feb. 16	....	....	16.41	15.29
Mar. 18	....	....	10.04	13.96

* Date husked.

HYGROSCOPIC MOISTURE IN SHELLED CORN

Shelled corn, like many other materials, is hygroscopic, and loses moisture to the atmosphere or gains moisture from it until the humidity of the latter is in equilibrium with the hygroscopic moisture of the grain. No data were found in the literature concerning the moisture content of shelled corn when in equilibrium with atmospheres of different relative humidity. A series of experiments was accordingly undertaken with a view to obtaining such data. Three samples of corn were used for this purpose: (1) Boone County white dent corn of the 1919 crop, supplied by the Office of Cereal Investigations, United States Department of Agriculture, and designated as Lab. No. B15; (2) Johnson County white dent corn of the 1920 crop grown at the Maryland Experiment Station, Lab. No. B32; (3) Sweet corn, Lab. No. B47, from the same source as B32. About 50 kernels of each of the three samples were spread out on pieces of paraffined wire gauze, and these suspended in the upper part of half-gallon museum jars. Five such jars were thus prepared, and the lower halves were filled with solutions of sulfuric acid in water, a different concentration being placed in each jar. These concentrations were so adjusted, using the Regnault tables,[2] that the resulting relative humidities of the atmospheres in the jars ranged between about 35 and 85 per cent at 25° C. The jars were placed in an incubator maintained at 25° C., and the grain remained exposed to the several atmospheres until no further change in weight took place. This required about three weeks, when the change in moisture content was considerable. The grain was then

[2] Landolt, Börnstein, Roth. Physikalish-Chemische Tabellen, 4 Auflage, p. 426. 1912.

removed and the percentage of moisture which it contained was determined; the specific gravity of the sulphuric acid solutions was also determined at the time the grain was removed, and the humidity data were reported on the basis of conditions prevailing at the close of the experiment rather than at the beginning.

The data resulting from these experiments are given in Table II, and represented graphically in Figure 4. These show consistent differences in the relative hygroscopicity of the three samples, with B32 the highest and B47 the lowest in that regard. Whether the fact that the latter was sweet corn has any bearing on its relative hygroscopicity is hardly determinable from the available data, but this seems probable from other considerations. The mean percentages of hygroscopic moisture in the three samples studied ranged from 8.25 per cent

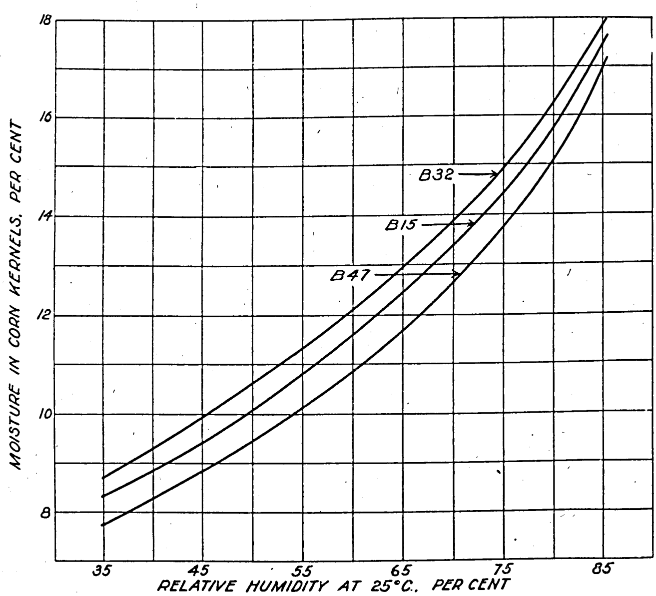

Figure 4. Hygroscopic Moisture in 1919 Crop Dent Corn (B 15), 1920 Crop Dent Corn (B 32), and 1920 Crop Sweet Corn (B 47), After Exposure to Atmospheres of Different Relative Humidity at 25° C.

at 34.8 per cent relative humidity (25° C.) to 17.57 per cent at 85.4 per cent relative humidity. It is thus evident that the percentage of moisture in corn may undergo considerable change when exposed to atmospheres of different humidity, providing the conditions of exposure are such that the movement of water vapor can take place. This depends, in turn, upon the size and shape of the parcel of grain, the material in which it is contained, the extent of air circulation, and other factors. It is probable that no considerable response to changes in atmospheric humidity will be experienced in handling and storing bulk shelled corn, since the exposure is too slight. Surface layers might be affected, but to so slight a depth that it would represent only a small fraction of the total bulk. Ear corn in cribs can respond somewhat more readily to such changes, and seed corn hung up in seed houses will doubtless show an even greater response.

TABLE II

HYGROSCOPIC MOISTURE OF SHELLED CORN EXPOSED TO ATMOSPHERES OF DIFFERENT RELATIVE HUMIDITY AT 25° C.

Relative humidity of atmosphere at 25° C.	Hygroscopic moisture			
	B 15	B 32	B 47	Average
Per cent	Per cent	Per cent	Per cent	Per cent
34.8	8.32	8.69	7.73	8.25
54.1	10.62	11.18	10.04	10.61
71.3	13.66	14.31	12.96	13.64
78.7	15.23	15.80	14.10	15.04
85.4	17.61	17.95	17.15	17.57

DISTRIBUTION OF MOISTURE IN THE CORN KERNEL

Attention has been called by Babcock (1912) to the distribution of moisture in corn kernels which had been immersed in boiled water for 24 hours. Under such circumstances he found the embryo contained about 52 per cent of water, while the "starchy portion" contained about 32 per cent. In air-dried corn the embryo contained 5.62 per cent of moisture, the starchy portion 7.10 per cent.

TABLE III

DISTRIBUTION OF MOISTURE BETWEEN THE GERM AND THE DEGERMINATED RESIDUE OF WHITE DENT CORN

Moisture in		
Entire kernel	Germ	Degerminated residue
Per cent	Per cent	Per cent
13.39	10.05	13.47
14.32	11.25	14.51
15.11	12.32	15.35
16.94	15.51	17.12
19.17	21.73	18.85
21.77	26.83	21.15
24.50	36.25	23.04

In order to supplement these data by determining the distribution of moisture between germ and non-germ structures through the range of moisture content of commercial corn, several portions of the white

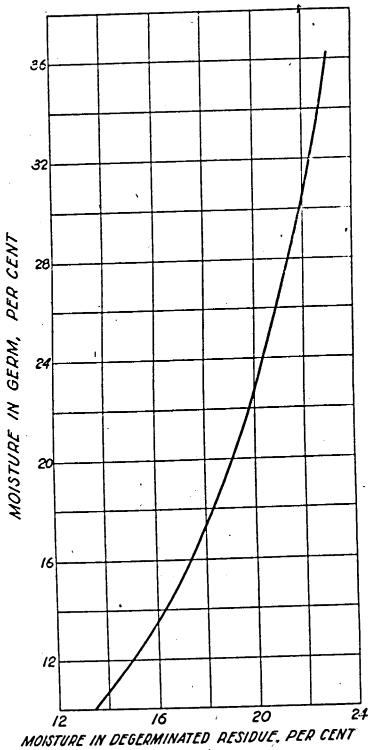

Figure 5. Percentage of Moisture in Germ, and Degerminated Residue of Corn Kernels

dent corn sample, B15, were each brought to a different moisture content by the addition of water. These were then placed in a refrigerator for four days to allow the distribution to proceed to completion. The germ, or embryo, was then dissected out with a small scalpel, and the moisture in the germ and the degerminated residue was determined. Table III and Figure 5 show the moisture content of the degenerated residue to have been higher than that of the embryo, with increasing moisture content until the kernel contained in excess of 18 per cent of moisture. From this point on, the germ contained more moisture than the residue until at the higher levels the ratio was about 1.5 to 1. It thus appears that in No. 3 corn containing somewhat more than 17.5 per cent of moisture, the percentage of moisture in the germ and in the residue of the kernel is approximately the same.

RELATION BETWEEN MOISTURE CONTENT AND RESPIRATION IN NORMAL CORN

Earlier investigations indicated that increasing the moisture content of seeds and tubers accelerated their rate of respiration. Lund (1894) made such an observation in the case of roots and tubers. Kolkwitz (1901) reported that barley kernels with from 10 to 11 per cent of moisture respired very feebly, liberating ⅓ to 1½ milligrams of carbon dioxid per kilo in 24 hours. On moistening them the intensity of respiration increased, with a "critical turning point" at 15 to 16 per cent of moisture. At 20 per cent of moisture respiration was much stronger, while at 33 per cent about 2000 milligrams of carbon dioxid were respired.

Qvam (1906) also observed an increased rate of respiration in barley as the percentage of moisture was increased.

White (1909) found that cereals respire appreciable quantities of carbon dioxid in an "air-dried" condition, while drying them for 8 days at 45° C. depressed respiration to a level which resulted in quantities of respired carbon dioxid too small to be determined by the methods employed.

Duvel (1904), in studying the vitality of stored seeds, observed that the concentration of respired carbon dioxid in closed containers was increased with increasing percentages of moisture in the seed. At the same time there was a reduction in the percentage of viable seed.

Bailey (1917) reported observations of stored wheat in elevators at Duluth. Wheat containing 15.5 per cent of moisture was stored in an elevator bin September 11, 1914, and did not respire vigorously enough to raise its temperature above 72° F. during the succeeding fall months. Another lot of wheat containing 16.5 per cent of moisture, stored at the same time, was actively heating in 49 days, at which time it had reached a temperature of 80° F.

Experiments of Duvel and Duval (1919), to which reference has already been made, establish a correlation between moisture content and heat liberated as the result of respiration. One series of these investigations illustrates the effect of moisture content on rise of temperature. The corn in this experiment was loaded in box cars at Baltimore on April 14, 1910, and hauled to Chicago and back, and unloaded on May 11, 1910.

Car no.	Moisture in corn	Average temperature of corn when—	
		Loaded April 14	Unloaded May 11
	Per cent	°F.	°F.
1	19.8	58	139½
2	18.6	52	84
3	17.8	54	82½
4	17.4	54	58½
5	16.7	58	62

The difference between initial and final temperature in car No. 4 and car No. 5 is about the same, and suggests that the change in temperature in these instances may be attributed to heat absorbed from the atmosphere. Neither changed temperature significantly during the period of the experiment.

Bailey and Gurjar (1918) found that increasing the moisture content of wheat accelerated the rate of respiration. The relative increase in carbon dioxid respired per unit increase in moisture content is shown in Table V.

For the purposes of these corn-respiration studies, six samples of white and yellow dent seed corn grown in Texas, Arkansas, Missouri, Iowa, and Minnesota were secured, and one sample of white flint corn from North Dakota. These were reported by the experiment station agronomists of the several states to be representative of the states in which they were produced. They accordingly represented wide extremes of dent corn types, from large-eared, late-maturing varieties of the south, to small, compact-eared, early-maturing varieties of the north. Any inherent differences in the respiratory activity of these different types should accordingly manifest themselves in the samples selected. To insure that no damaged kernels or foreign substances were present to affect the results, each sample was carefully screened and hand picked to remove such material. Germination tests showed the cleaned samples to be normally viable.

The laboratory numbers and a description of the samples are given in the following table:

Lab. No.	Variety	Color	Grown at	Crude protein (N X 6.25)	Wt. per 1000 kernels
				Per cent	Grams
6854	Minnesota No. 13	Yellow	St. Paul, Minn.	10.55	260
6855	White flint	White	Fargo, No. Dak.	11.31	288
6858	Tuxpan	White	Dallas, Texas	10.81	368
6859	Reid's Yellow Dent	Yellow	Ames, Iowa	10.62	400
6862	Reid's Yellow Dent	Yellow	Columbia, Mo.	9.75	342
6860	Commercial White	White	Columbia. Mo.	10.93	444
6861	Mexican June	White	Phoenix, Ariz.	11.18	336

Each sample was subdivided into eight or ten portions, and each portion was then brought to a different moisture content by the addition of water. The percentages of moisture thus ranged from the original moisture content of the air-dry corn (10.2 to 11.7 per cent) to about 18 per cent. These limits were imposed because it is within this range that respiration reaches a sufficiently high level under certain commercial conditions to raise the temperature of bulk grain to a point where damage will ensue. Duvel and Duval (1913), in a series of experiments with corn in box cars, found a carload containing 16.0 per cent of moisture and loaded on May 11, 1911, to be actively heating on June 3, 1911, with a temperature of 100.2° F. Shanahan, Boerner, and Leighty (1910) report entire holds of corn shipped in vessels from America, containing as low as 15.6 per cent of moisture, to be in a heating or hot condition when examined in Europe (note, for example, cargo 170); while considerable percentages of certain holds were found in a heating or hot condition when the moisture content was under 15 per cent (note cargoes 127, 168, 169, and 172). The total percentage of American corn found heating or hot on arrival in Europe during the three seasons from 1905 to 1908 was as follows (from Shanahan, Boerner, and Leighty's paper).

Moisture content Per cent	Heating or hot on arrival Per cent
12.1 to 14	6.6
14.1 to 16	7.7
16.1 to 18	14.9
18.1 to 20.6	12.8[3]

[3] The fact that this percentage is lower than for corn containing from 16.1 to 18 per cent of moisture was due to favorable shipping conditions.

Boerner (1919) studied several cargoes of American corn en route to European ports, and found in certain instances that corn containing less than 18 per cent of moisture was hot or heating near the surface on arrival at the port of destination. Seasonal conditions, proximity to engine-room bulkheads, and access to air, functioned with moisture content in determining the rate and extent of heating.

Several samples of heating corn which contained less than 17 per cent of moisture were supplied for these studies by the Minneapolis laboratory of the Office of Federal Grain Supervision. These were drawn from car lots inspected during the last half of June and the first week of July, 1920. From these considerations it appears that corn containing less than 18 per cent of moisture is likely to heat when handled in bulk, and that data establishing the comparative respiratory rate between that limit and that of dry corn will be of the most service at this time.

In conducting these studies, triplicate determinations of the rate of respiration of each portion of the several corn samples were made at a temperature of 37.8° C. (100° F.). Approximately two hundred determinations are accordingly included in the studies of the seven seed-corn samples. The averages of these determinations are given in Tables XVII to XXIII in the appendix. Graphs were drawn for each of the seven samples, and from these the rates of respiration at even percentages of moisture from 11 to 18 per cent were computed by interpolation. The samples were then classified into "northern" and "southern" groups, those grown in North Dakota, Minnesota, and Iowa being included in the first group, while those grown south of Iowa constituted the second group. The average rate of respiration of the corn in the two groups was then calculated. It appears from these data, which are given in Table IV and shown graphically in Figure 6, that the corn samples in the northern group respired somewhat more vigorously than those in the southern group, altho the differences are not appreciable until the moisture content exceeds 15 per cent. Such a difference is perhaps to be anticipated, since early maturity in the northern-grown varieties may be correlated with a higher rate of respiration in the germinating seed, for rapid growth and development of the seedlings of early maturing varieties may possibly

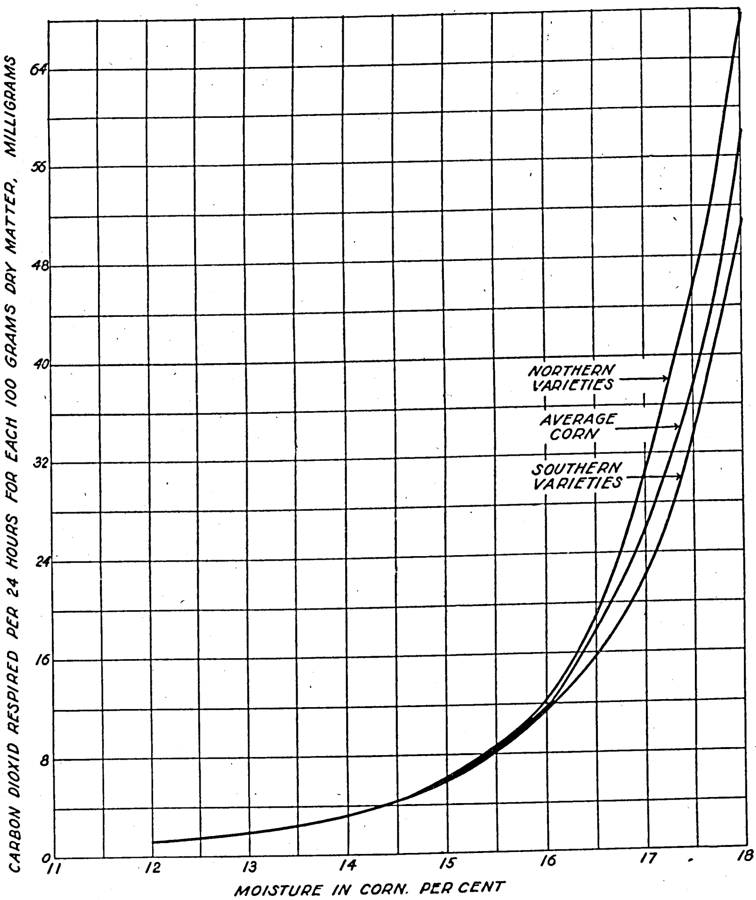

Figure 6. Respiration of Northern Varieties, Southern Varieties, and Average Corn

contribute to the relative rate of development. This is suggested by the work of Reed and Holland (1919), who state in the opening paragraph of their paper "If we assume that growth is a dynamic process and the organism is produced as its end-product, certain relations ought to exist between the size of the organism at any given time and the final size attained in time, T." They then present data in support of such an assumption and establish that growth rate of sunflower plants approximates closely the curve of an autocatalytic reaction. While their observations began with plants already 10 centimeters high, the writer believes it might properly be assumed that physiological responses which result in an early maturity of a plant would also be reflected in rate of germination of the seeds of that plant. If a higher germination rate is encountered in certain corn varieties than in others, this should be expected to be correlated with either (a) a higher concentration of enzymes concerned with the progress of germination, or (b) a lower optimum temperature for such enzymes, resulting in more rapid hydrolytic and other enzymic reactions at the comparatively low temperatures frequently prevailing in the soil at the time of corn planting. The possibility of establishing such correlations has suggested itself, but must be reserved for later studies.

Differences observed in the respiratory rate of northern and southern grown corn varieties are hardly great enough to justify a classification on the basis of point of origin or variety in standardizing commercial corn with respect to keeping qualities.

TABLE IV

RATE OF RESPIRATION OF NORTHERN AND SOUTHERN CORN VARIETIES AT EVEN PERCENTAGES OF MOISTURE

Moisture	Carbon dioxid respired per 24 hours for each 100 grams of dry matter		
	Northern varieties	Southern varieties	Average
Per cent	Mgm.	Mgm.	Mgm.
11	0.77	0.70	0.73
12	1.19	1.15	1.17
13	1.91	1.75	1.82
14	3.21	3.17	3.18
15	6.20	5.91	6.02
16	12.21	11.55	11.83
17	30.98	22.16	25.94
18	67.73	50.86	58.09

The acceleration of respiration with increasing moisture content was then calculated, and these data are given in Table V. In making these calculations the formula $\frac{Km - Km-1}{Km-1}$ was employed, in which Km represents the rate of respiration at any particular percentage of moisutre *(m)*, and $Km-1$ the rate when the sample contained 1 per cent less of moisture $(m-1)$. The values thus represent the fractional increase in respiratory rate by intervals of 1 per cent change in moisture content. For example, the rate of respiration of average sound seed corn, as shown in Table V, was increased by 56 per cent when the moisture content was increased from 11 to 12 per cent.

It appears that the relative acceleration with increasing moisture is much more uniform than was found in the experiments with wheat previously reported by Bailey and Gurjar (1918). When the moisture content of sound spring wheat was increased, a sharp break in respiratory rate appeared between 14 and 15 per cent of moisture, while the relative acceleration increased further with progressive increases in moisture content above the latter figure. In the case of these corn samples no such sharp break in the curve appears, altho a uniform increase in relative acceleration with increasing moisture content is apparent from the data given in Table V.

TABLE V

ACCELERATION OF RATE OF RESPIRATION OF SOUND CORN AND SOUND SPRING WHEAT WITH INCREASING MOISTURE CONTENT

Cereal	Acceleration between the following percentages of moisture						
	11 to 12	12 to 13	13 to 14	14 to 15	15 to 16	16 to 17	17 to 18
Corn	0.56	0.60	0.75	0.89	0.97	1.19	1.24
Spring wheat.........	...	0.16	0.17	0.66	1.41	3.02	...

Reasons for such marked acceleration of respiration as result from comparatively small increases in moisture content are still within the realm of hypothesis. The author (1917) has previously suggested that these are to be found in part at least in the colloidal properties of the materials which chiefly constitute the kernel. When "dry," the limited hygroscopic water present is held by the colloids under high tension. Hales (1727), nearly two centuries ago, observed that germinating pea seeds would swell under a pressure equivalent to 83.5 kilos. Rodewald (1895) computed that dry starch imbibed water in swelling under a pressure of 2605 kilograms per square centimeter, or 2523 atmospheres. Materially higher values were assigned by Sachs (1882), and Patten (1907) suggests that Rodewald's value is too low. It has even been estimated that the pressure in such instances is sufficient to cause the imbibed water to possess certain properties of a solid. Increasing the moisture content diminishes the pressure under which each successive addition is held by the colloidal system. Thus Shull (1913) shows that in an air-dry Xanthium seed which contains from 8 to 9 per cent of hygroscopic moisture, the imbibition force is 965 atmospheres, and that the addition of 7 per cent more water reduces the imbibition force to 375 atmospheres. The possibility of diffusion of the water-soluble substances present must be progressively enhanced by successive additions of water to the kernel. This accelerated diffusibility would affect not alone the soluble solids, as sugars and mineral salts, but also gases, as oxygen and carbon dioxid. Respiration could hardly proceed unless the substances involved in the chemical reactions move, chiefly by diffusion, to the seat of respiration. If, as Osterhout (1917) postulates, oxidations proceed chiefly in the nucleus of the cell, a diffusion within the cell would be necessitated, if not from cell to cell and tissue to tissue. Certainly the gases involved must move through cells and tissues, particularly in aerobic respiration.

Bearing on this hypothesis are the results of measurements made with the electrode designed by Zeleny (1909), modified somewhat so that the two metal points of copper and zinc respectively are mounted

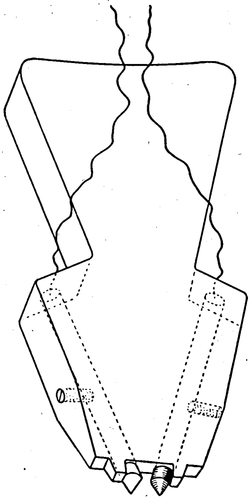

Figure 7. Modified Zeleny Electrode

in a vulcanite handle and with the axes of their points parallel to each other. The modified electrode is shown in Figure 7. These two points of dissimilar metal are pressed into the germ of the corn kernel, and the system Cu—Germ—Zn thus constitutes a small voltaic cell. The current flowing through this cell is a function of the percentage of moisture in the germ. This was observed by Zeleny, and confirmed by tests made in these studies. A composite sample of No. 2 mixed corn was divided into seven portions, each of which was brought to a different percentage of moisture, ranging from 13.89 per cent to 17.70 per cent, by the addition of varying quantities of water. These portions were then allowed to stand for several days in order to allow the distribution of water in the kernels to proceed to completion. The points of the Zeleny electrode were thrust into the embryos of corn kernels taken from each lot, and the deflections of a d'Arsonval galvanometer were noted when connected to this cell. The electrode points were forced into the germs under a uniform pressure maintained by a simple mechanism consisting of a lever and coiled spring. More uniform results could be obtained in this manner than when the electrode handle was held in the hand in introducing the points. Average deflections of each of the seven lots, together with the moisture content, are given in Table VI and shown graphically in Figure 8. During several preliminary tests it developed that the deflections resulting from measurements made with different kernels taken from the same sample, and presumably having the same moisture content, varied widely when the kernels tested were of varying size and structure. Size of the germ in particular seemed to affect the galvanometer deflections. In the series reported in Table VI, those kernels differing materially from the average in shape and size of germ were rejected, and tests were made only of those approaching the average in these regards.

The cells did not give the maximum reading with the galvanometer immediately upon inserting the metallic points into the corn embryos. About 30 seconds were usually required for the galvanometer coil to deflect to the maximum, after which it gradually rotated back to its original position, indicating a polarization of the cell. Maximum deflections observed were recorded in each instance.

Electrical potentials of these cells were also determined, by connecting the wire leads from the electrodes to the E. M. F. connectors of a Leeds and Northrup Type K potentiometer. While this instrument is probably not well adapted to the measurement of potential from such sources, it was evident that changes in potential on increasing the moisture content of the grain were of small magnitude compared with the changes in galvanometer deflections. The latter being a function of current, it is evident that the current flowing through such a cell is low when dry corn germs are tested, while the current increases decidedly on raising the moisture content, indicating a comparatively enormous decrease in the electrolytic resistance of the cell, the E. M. F. of which is fairly constant.

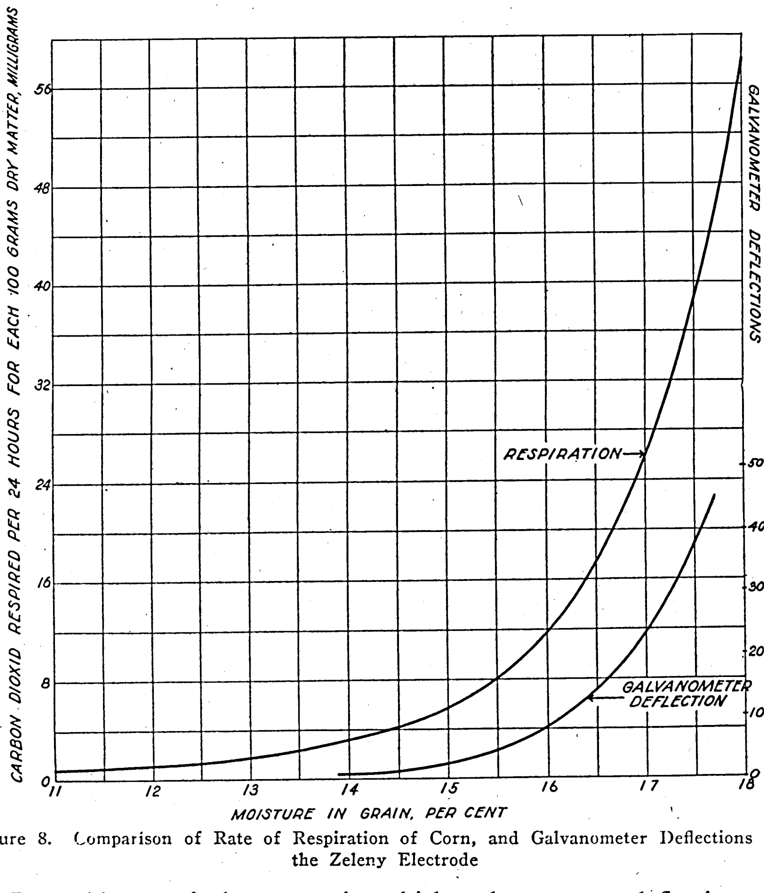

Figure 8. Comparison of Rate of Respiration of Corn, and Galvanometer Deflections with the Zeleny Electrode

Resemblance of the curve in which galvanometer deflections are plotted against moisture content, to the curve in which respired carbon dioxid is plotted against moisture content, shown in Figure 8, suggests that the same phenomena are operative in determining electrolytic resistance of the corn germ and respiratory activity of normal grain. Resistance encountered by ions in moving between the poles of the electrode is probably responsible in large part for the high electrolytic resistance of dry corn germs, while the hypothesis is advanced that resistance to the free movement of ions and molecules through the same material may likewise be responsible for reduced respiration in dry grain. The relation of the limited quantity of water present to the colloids of the grain is believed to determine the comparative rate of movement of dissolved solids and gases in the system.

TABLE VI

POTENTIALS AND GALVANOMETER DEFLECTIONS RESULTING FROM THE INSERTION OF THE Cu-Zn ELECTRODE INTO GERMS OF KERNELS OF VARYING MOISTURE CONTENT

Sample	Moisture	Galvanometer deflection with Cu-Zn electrode
46b	13.89	0.7
46c	14.52	1.7
46g	15.16	3.5
46d	16.00	7.7
46e	16.51	14.2
46h	17.23	29.9
46f	17.70	45.0

RESPIRATION OF CORN DURING THE CURING PROCESS

In Table I it was shown that the moisture content of a lot of white dent corn diminished during the curing process. The respiratory activity of the same lot of corn was determined at intervals while curing. The results are shown in Table VII, together with the interpolated rate of respiration of sound corn containing the same percentage of moisture six months or more after harvest. Unfortunately only one sample of the corn stored in the barn was subjected to a test of respiratory activity, this work being incidental to the other studies, and no provision having been made for sufficient material to carry out an extended series. It appears from the limited data available that the rate of respiration is lower in freshly harvested corn than in corn of the same moisture content several months after harvest. The greatest relative difference was encountered in the corn which was shelled on November 4, 1920, from ears curing in the laboratory. In this sample the rate of respiration was only about one-fourth that of normal corn a few months after harvest. A sample of corn in the barn taken on December 3, 1920, or one month later, which contained nearly the same percentage of moisture, namely 17.9 per cent, respired 19 milligrams of carbon dioxid, or nearly twice as much as that shelled from the laboratory-cured sample on November 4.

It appears that a condition similar to dormancy may be involved in these reduced rates of respiration which corn exhibited in the first few weeks following harvest. Crocker (1916), in summarizing the factors contributing to dormancy of seeds, states that in certain species this may be due to inhibition or retardation of the passage of gases to or from the embryo by the testa, resulting in an accumulation of carbon dioxid within the tissues of the embryo or an insufficient supply of oxygen for germination. While corn kernels are not dormant in the sense usually implied by that term, and will germinate shortly after harvest, there might nevertheless be a reduced permeability to the gases involved in respiration. At any rate this seems the most logical explanation of the reduced rate of respiration observed in the grain when first harvested. It is probable that after a period of from four to six weeks the conduct of the grain in this regard rapidly approaches the normal for ripened and cured corn. Reduced respiratory activity early in the curing process is fortunate and of advantage in that the liability of damage resulting from excessive respiration during the critical period when the moisture content of the grain is high, is thus diminished.

TABLE VII

RESPIRATION OF CORN DURING PROCESS OF CURING COMPARED WITH CORN OF THE SAME MOISTURE CONTENT SIX MONTHS OR MORE AFTER HARVEST

Date sampled	Moisture in grain	CO_2 respired per 100 grams dry matter in each 24 hours	CO_2 respired per 100 grams dry matter in each 24 hours by corn of same moisture content 6 months after harvest
Corn cured in laboratory			
1920	Per cent	Milligrams	Milligrams
October 28	25.77	116.09	....
November 4	17.80	10.97	46.70
November 12	14.41	2.18	4.07
November 29	12.05	1.24	1.20
Corn cured in barn			
December 3	17.90	19.00	47.00

After the period of reduced respiration there appears to be no material change in the respiratory rate of sound grain with further lapse of time during the remainder of the season, except such as accompanies desiccation of the grain. This is indicated by the results of an examination of several samples of the 1919 corn crop drawn from car lots of commercial corn by the Office of Federal Grain Supervision, at Minneapolis, during June and July, 1920. Cars that were sound and cool on arrival respired at about the same rate as the average seed-corn samples (Table IV) when the moisture content of the latter was increased by additions of water and the respiratory rate determined three days later. The moisture content, grade, and rate of respiration of these commercial lots of corn are shown in Table VIII.

TABLE VIII

RESPIRATION OF SOUND COOL COMMERCIAL DENT CORN OF THE 1919 CROP SAMPLED AT MINNEAPOLIS DURING THE SUMMER OF 1920

Sample mark	Date sampled	Grade	Moisture	Wt. per bushel	Carbon dioxid respired per 24 hours by each 100 grams dry matter
	1920		Per cent	Lbs.	Milligrams
7706	June 17	3 yellow	15.6	56.2	8.52
7956	June 30	2 mixed	15.3	55.5	10.26
7959	June 30	3 yellow	15.8	54.3	12.03
6	July 1	6 white	15.1	56.2	7.55
9	July 1	3 mixed	15.2	55.8	7.02
112	July 7	2 mixed	15.0	56.8	7.70

EFFECT OF "FOREIGN MATERIAL AND CRACKED CORN" ON RATE OF RESPIRATION

In the federal standards for corn appear maximum limits of foreign material and cracked corn which may be present in each of the six numerical grades. Less is allowed in the higher grades, the limit progressively increasing from No. 1 to No. 6 corn. In grading corn this material is separated by sifting the corn on a metal sieve perforated with round holes 14/64 of an inch in diameter. The trade appears to be of the opinion that the keeping qualities of bulk shelled corn are impaired by the presence of broken material. In order to ascertain the effect of such material, a series of samples was obtained from the Baltimore laboratory of the Office of Federal Grain Supervision, which had been graded on the basis of their content of foreign material and cracked corn. Five samples of No. 4 mixed corn were composited. These contained from 4.2 to 5 per cent of foreign material and cracked corn, with an average of 4.7 per cent. A like number of sample grade mixed corn samples were composited which contained from 7.4 to 10 per cent of foreign material and cracked corn, with an average of 8.7 per cent. The composite samples were practically alike in other particulars as is evident from the data in Table IX.

TABLE IX

CHARACTERISTICS OF THE NO. 4 MIXED AND SAMPLE GRADE MIXED CORN COMPOSITE SAMPLES USED IN RESPIRATION STUDIES

Grade	Moisture	Wt. per bushel	Damaged kernels		Foreign material and cracked corn
			Total	Heat damage	
	Per cent	Lbs.	Per cent	Per cent	Per cent
No. 4 mixed........	12.9	56.0	2.8	0.0	4.7
Sample grade mixed.	13.1	56.5	2.4	0.0	8.7

These composite samples were each divided into four portions, and each of these was in turn brought to a different moisture content by the addition of water. After three days the rate of respiration was determined in the usual manner, with the results shown in Table X, and graphically in Figure 9. The latter also includes a portion of the curve for sound, clean seed corn (Figure 6), and indicates that foreign material and cracked corn appreciably accelerate respiration of the bulk at all percentages of moisture within the range studied. Injury of certain vegetative structures has been observed by other investigators to increase their rate of respiration. It is doubtful if in material where respiration is at so low a level as in these corn samples the mechanical injury has, in itself, any pronounced effect on respiration. More probably the improved conditions for gaseous diffusion to and from the respiring cells which result from cracking or crushing the kernel are responsible for part of the increased respiration. Improved opportunity for the growth of fungi of various sorts on the broken fragment, particularly when damp, may contribute also to the totality of respiratory phenomena. Whatever the actual cause, there is evidently a greater hazard in handling corn containing an appreciable quantity of cracked corn than in handling sound clean grain under similar conditions.

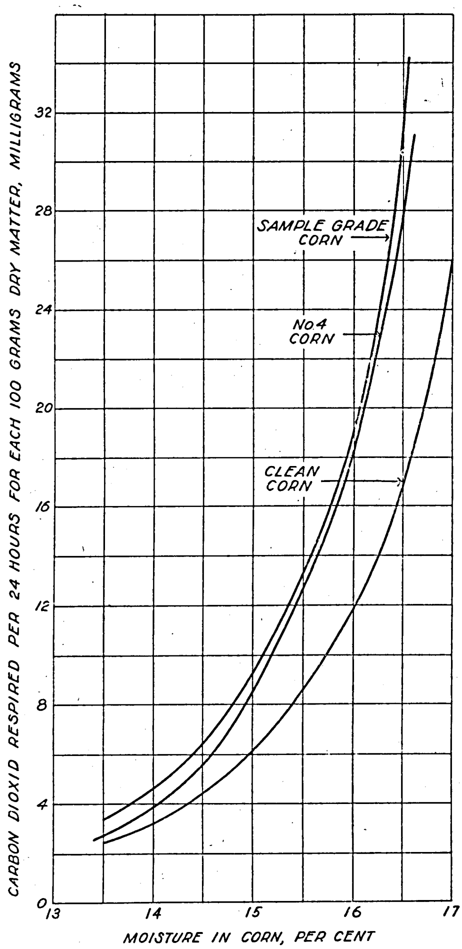

Figure 9. Effects of Foreign Material and Cracked Corn on Rate of Respiration

TABLE X

RESPIRATION OF SAMPLES CONTAINING FOREIGN MATERIAL AND CRACKED CORN

No. 4 mixed corn with 4.7 per cent of foreign material and cracked corn		Sample grade mixed corn with 8.7 per cent of foreign material and cracked corn	
Moisture	Carbon dioxid respired in 24 hours for each 100 grams dry matter	Moisture	Carbon dioxid respired per 24 hours for each 100 grams dry matter
Per cent	Milligrams	Per cent	Milligrams
13.40	2.56	13.50	3.35
14.63	6.14	14.97	9.16
15.62	13.83	15.68	15.02
16.67	31.14	16.56	34.28

RESPIRATION OF SPROUTED CORN

Bailey and Gurjar (1920) found that sprouted wheat kernels that had been dried until their moisture content was between 12 and 16 per cent respired more vigorously than sound wheat of the same moisture content. Within certain limits the length of time that germination of the grain proceeded appeared to be a function of respiratory rate. Thus wheat germinated for forty-eight hours and then dried respired at a higher rate than another portion of the same wheat sample which had been allowed to germinate for only twenty-four hours. Similar results were obtained in this study of corn. The seed laboratory of the Maryland experiment station germinated two portions of Boone County white dent corn (Lab. No. B15) in the manner usual to the testing of seed corn for three and five days. After drying the germinated kernels to a moisture content of about 11 per cent, each of the samples was subdivided into six portions, to which varying quantities of water were added. The rate of respiration of these was determined after a lapse of three days. Table XI shows the carbon dioxid respired by each of these portions, as well as by normal or ungerminated corn of the same original sample containing different percentages of moisture. The same data presented graphically in Figure 10 indicate that within the limits of moisture content studied, the germinated corn respired at a considerably higher rate than the ungerminated corn of the same moisture content. Sprouted or germinated corn would accordingly tend toward heating more readily when stored than sound corn of the same moisture content.

In the studies of germinated wheat already referred to, it developed that the ratio of respiratory rate in the several samples was not far different from the ratio of their reducing sugar content. This suggested that possibly accelerated respiration of sprouted grain might result from an increased concentration of those simple hexose sugars which are generally believed to constitute the principal substrate for the enzyms concerned with respiration. It seems improbable that so simple an explanation will suffice. Doubtless more factors are operative than the mere concentration of reducing sugars. The colloidal condition of the hydrophyllic colloids in the damaged grain may conceivably play an important part in the altered respiration. Certain of these colloidal substances are known to undergo significant changes during germination, which involve progressive transformations to non-colloidal or crystalline compounds. Their water-imbibing capacity must be modified and reduced at the same time, and diffusion facilitated in the tissues of which they constitute an important part. The actual concentration of certain enzyms also apparently increases during germination, and possibly those enzyms involved in respiration may similarly increase.

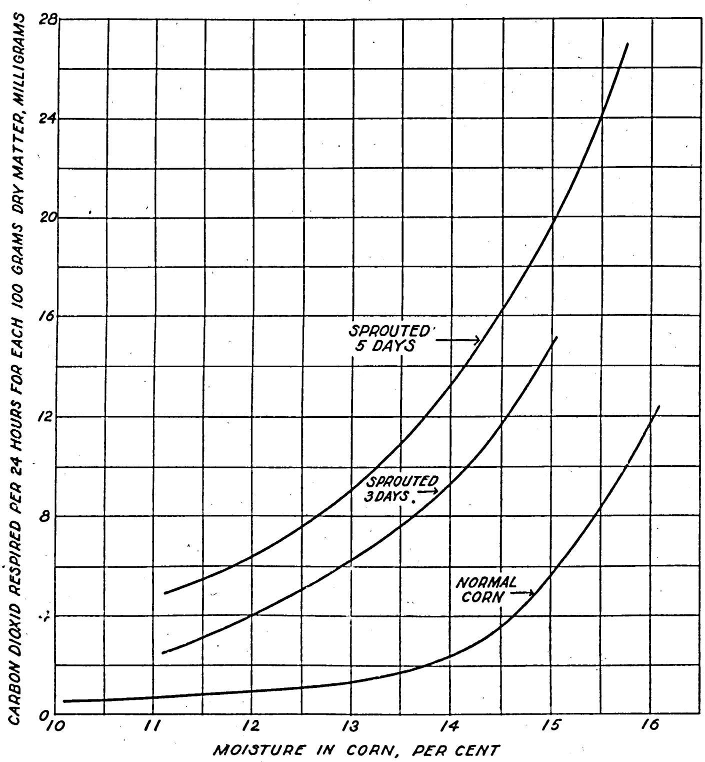

Figure 10. Respiration of Normal and Sprouted Corn Kernels

TABLE XI
RESPIRATION OF NORMAL AND GERMINATED BOONE COUNTY WHITE DENT CORN

Moisture	Carbon dioxid respired per 24 hours for each 100 grams dry matter
Normal or ungerminated corn	
Per cent	Milligrams
10.09	0.55
13.39	1.68
14.32	2.91
14.64	2.96
15.11	6.27
15.72	9.67
16.09	12.38
Kernels germinated 3 days	
11.09	2.51
12.38	4.76
12.84	6.03
13.19	6.61
14.30	10.61
15.03	15.04
Kernels germinated 5 days	
11.12	4.96
12.60	7.79
13.70	11.66
13.87	13.11
14.80	18.10
15.77	27.02

RESPIRATION OF HEAT DAMAGED CORN

It was developed in the opening paragraphs of this paper that heating corn will frequently reach comparatively high temperatures, occasionally as high as 65° C. (149° F.). The trade has noted, and controlled experiments have confirmed the opinion, that if the temperature exceeds 37.8° C. (100° F.) the kernels become discolored, while if the temperature continues to rise the kernels in time become "mahogany" or dark brown in color throughout. Such grains possess a peculiar characteristic odor, and a friable texture. The kernels generally fail to germinate when the damage is at all considerable. Besley and Baston (1914) described a method for determining the acidity of corn, and established a correlation between the comparative acidity (by titration) and the soundness of various corn samples. While forms of unsoundness other than heat damage are involved in instances of increased acidity, they indicate that when heating of sound corn occurs, the acidity increases. This is shown by the acidity (stated in terms of the number of cubic centimeters of one-hundredth normal alkali required to neutralize the acid in 10 grams of corn) of samples taken at different stages of marketing, in the following table (Besley and Baston, p. 11):

Kind of corn	Acidity	
	Average	Range
	c.c.	c.c.
Corn selected for seed	17 2	13.6 to 23.8
Country elevator receipts and shipments	19.4	14.5 to 50.8
Terminal market receipts	20.4	11.7 to 66.4
Loaded at seaboard for export	20.2	12.4 to 32.0
Discharged at foreign ports	30.4	16.0 to 110.8

They examined a cargo of corn with an initial temperature of 59° F., and an acidity of 20.4 cc., that when discharged at a European port had a temperature of 96° F., and an acidity of 29.8 cc. In nine cargoes the acidity of the corn when discharged varied directly with the temperature at that time. When the temperature was below 50° F. the acidity was 21 cc., while cargoes with a temperature above 100° F. at the time of discharge had an average acidity of 42.5 cc. Separations of sound and damaged kernels in approximately 3000 samples were made during parts of three seasons, and in these they found the following degrees of acidity (Besley and Baston, p. 40):

	Degree of acidity
Sound kernels	19.5
Broken kernels	22.5
Damaged kernels, exclusive of heat damage	41.2
Slightly heat-damaged kernels	41,8
Badly heat-damaged kernels	50.8

A graph included in their paper shows the acidity of the germ of damaged corn to be materially greater than that of the degerminated residue. Thus in No. 4 and sample-grade corn the degree of acidity of the degerminated kernels was about 18 cc., while for the germs of the same kernels it was about 90 cc. The source of titrable acidity is thus apparently in the germ.

Hydrogen ion concentration of certain typical sound and damaged corn samples used by the writer in these respiration studies was determined, and it was found to be generally higher in the damaged grain. This is shown by the data in Table XII. Sound corn samples possessed a lower hydrogen ion concentration than pH 6.2 ($[H]^+ = 0.62 \times 10^{-6}$), while the damaged corn samples were on the acid side of pH 6. ($[H]^+ = 0.99 \times 10^{-6}$), These are not wide differences, considering the badly damaged condition of such material as is represented by samples B1 and B2, and because of this fact the electrometric determination of hydrogen ion concentration is of limited value in determining the extent of damage represented in such material.

Since the work of Besley and Baston established that acidity increased chiefly in the germ or embryo of the kernel when the latter became damaged, a study was made of the hydrogen ion concentration of germ and degerminated portions of sound and damaged corn.

TABLE XII

Hydrogen Ion Concentration of Sound and Damaged Corn

Lab. No.	Description	pH
Sound corn		
B 15	Boone County white dent seed corn	6.29
B 11	No. 2 yellow corn from Baltimore	6.37
B 13	No. 2 mixed corn from Baltimore	6.24
Damaged corn		
B 1	Damaged kernels, including heat-damage	5.95
B 2	Badly heat-damaged kernels	5.95
B 39	Sour and heating corn	5.65
B 15a	Same as B 15 after sprouting 5 days	5.72

Samples B15 and B39 were used for this purpose, with the results shown in Table XIII. From this it appears that the hydrogen ion concentration of sound corn germs may be decidedly less than the degerminated residue of the same kernels. The hydrogen ion concentration of damaged corn germs is somewhat higher than that of the degerminated residues of such kernels, but the difference is surprisingly small in view of Besley and Baston's findings. The small differences must be attributed to the high buffer action of germ extracts.

TABLE XIII

Hydrogen Ion Concentration of Germs and Degerminated Residues of Sound and Damaged Corn Kernels

Lab. no.	Description	Hydrogen ion concentration (as pH)		
		Whole kernels	Germ	Degerminated residue
B 15	White dent seed corn	6.29	6.75	5.78
B 39	Sour and heating corn	5.65	5.48	5.65

In connection with these determinations of hydrogen ion concentration it was observed that the pH changed in the direction of increasing acidity with the lapse of time after grinding. Thus the pH of freshly ground meal from Lab. No. B11 was 6.37, while four months after grinding it was 5.41, a change of nearly one unit in terms of pH, or nearly ten times in terms of hydrogen ion concentration. Similar changes were observed in other samples, indicating that even with dry, sound material such determinations must be made immediately after grinding the corn.

Another observation of interest in this connection is that the ratio of meal to redistilled water in preparing extracts for electrometric hydrogen ion concentration determinations may apparently vary between fairly wide limits without materially affecting the results. Ratios of meal to water of 1 to 5 and 1 to 10 resulted in small differences in the pH of the extracts.

Samples of hot and heating corn taken from box cars in the Minneapolis railroad yards by representatives of the Office of Federal Grain Supervision in the summer of 1920 were sent to the writer. These contained from 14.8 to 17.2 per cent of moisture. Their rate of respiration was determined, and these data are given in Table XIV. A comparison of these data with those shown for normal corn in Figure 11 indicate that these hot or heating lots of corn respired at a rate considerably above that of normal sound corn.

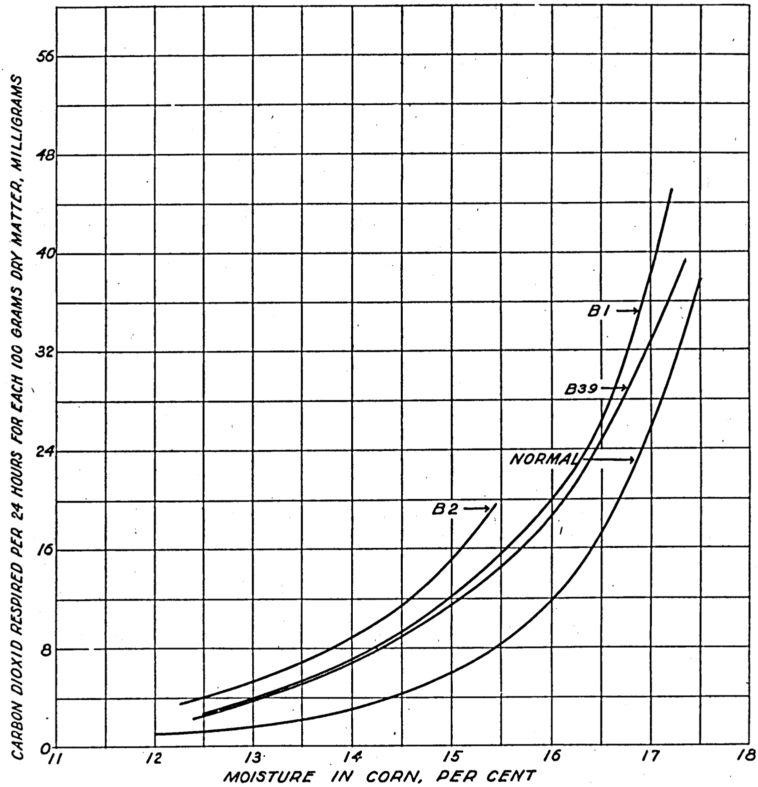

Figure 11. Comparative Respiration of Normal or Sound Corn, Badly Heat Damaged Corn (B 2), Sour and Heating Corn (B 39), and Corn Damaged in Various Ways (B 1)

Later the Board of Reviews, Office of Federal Grain Supervision, provided three samples of hand-separated corn kernels representing different forms of damage, for these studies. These samples may be described as follows:

B1. Kernels representing cob-rot, heat-damage, and other forms of damage common to the lower grades of commercial corn

B2. Badly heat-damaged, or mahogany kernels.

B39. Kernels from a lot of sour and heating corn not, however, badly heat-damaged.

TABLE XIV

RATE OF RESPIRATION OF CORN SAMPLES TAKEN IN A HOT OR HEATING CONDITION FROM CARS IN THE RAILROAD YARDS AT MINNEAPOLIS

Moisture	Carbon dioxid respired per 24 hours for each 100 grams of dry matter
Per cent	Milligrams
14.8	10.69
15.5	18.91
16.0	24.76
16.6	33.28
17.2	44.89

Portions of each of these samples were brought to different percentages of moisture by the addition of water, and their rate of respiration was determined. These data, as given in Table XV, and graphically in Figure 11, indicate respiratory rates decidedly above that of normal or sound corn. In fact it appears that any cause, such as sprouting or heating, which elevates respiration to a high level, leaves the respiratory "tone" or "pitch" above that of normal corn which has not been so treated. Even tho sprouting or heating grain be cooled and dried, this tendency persists, when comparisons are made with normal corn of the same moisture content and at the same temperature. Damaged corn is accordingly more likely to heat in storage and transportation and its moisture content must be 1.5 to 2 per cent lower than normal corn to insure that it will remain cool as well as the latter. Sour and heating corn was more pronounced in its tendencies toward excessive respiration than the mahogany, or badly heat-damaged, kernels. Possibly disorganization has gone so far in the latter that the "tone" has reached and passed the maximum, and is gradually approaching a lower level.

TABLE XV

RATE OF RESPIRATION OF DAMAGED CORN

Lab. No. B 1. Cob-rotten, heat-damaged, and other forms of damage	
Moisture	Carbon dioxid respired per 24 hours for each 100 grams of dry matter
Per cent	Milligrams.
12.48	2.64
14.04	7.32
15.53	17.08
16.55	25.87
17.21	45.08

TABLE XV—*Continued*

Lab. No. B 2. Badly heat-damaged or mahogany corn kernels

11.08	1.48
12.25	3.57
13.60	7.28
14.62	12.18
15.46	19.59

Lab. No. B 39. Sour and heating corn

12.39	2.34
13.03	3.78
14.36	8.19
15.14	13.13
17.35	39.31

INFLUENCE OF TEMPERATURE ON RATE OF RESPIRATION

Experience of the trade, as shown by observations of Duvel (1909), Duvel and Duval (1911, 1913), Bailey (1917), and Boerner (1919), has been that when grain begins to heat the rise of temperature per unit of time is greater as the temperature of the bulk becomes higher. Exceptions to this general rule are occasionally encountered when the weather becomes cool, and more heat is accordingly conducted into the atmosphere. Grain in vessels traversing chilled water might also respond to temperature changes of the latter, and the temperature of heating grain in exposed situations changes less rapidly than when not so exposed to cooling effects. Bailey and Gurjar (1918) found that the quantity of carbon dioxid respired by wheat was decidedly increased on raising the temperature by increments from 4° to 55° C. The most rapid change in rate was observed between 35° and 55° C.

In comparing the rate of respiration of shelled corn at two different temperatures, a large sample of composite No. 2 mixed corn, Lab. No. B46, was used. This was divided into six portions, each of which except the first was brought to a different moisture content by adding water. They were then placed in a refrigerator for three days to allow the moisture to penetrate the kernels. At this time the moisture content ranged from 12.08 to 17.70 per cent. Half of each portion was placed in a thermostat at 37.8° C., the other half in a thermostat at 27.8° C. The rate of respiration at 27.8° C. was appreciably lower, being somewhat more than half the rate at a temperature 10° higher. This is shown by the data in Table XVI, and graphically in Figure 12. The ratios at different percentages of moisture are quite uniform, indicating a similar response to increasing moisture content when corn is allowed to respire over a fairly wide range of temperature, providing all comparisons are made at the same temperature.

TABLE XVI

RESPIRATION OF COMPOSITE NO. 2 MIXED CORN AT 27.8 AND AT 37.8° C.

Moisture	Carbon dioxid respired per 24 hours for each 100 grams dry matter		Rate at 37.8° / Rate at 27.8°
	At 27.8° C.	At 37.8° C.	
	Milligrams	Milligrams	
12.08	0.68	1.28	1.88
13.89	1.51	2.85	1.89
14.52	2.67	4.98	1.86
16.00	7.21	14.32	1.99
16.51	9.13	17.96	1.97
17.70	23.32	42.21	1.81

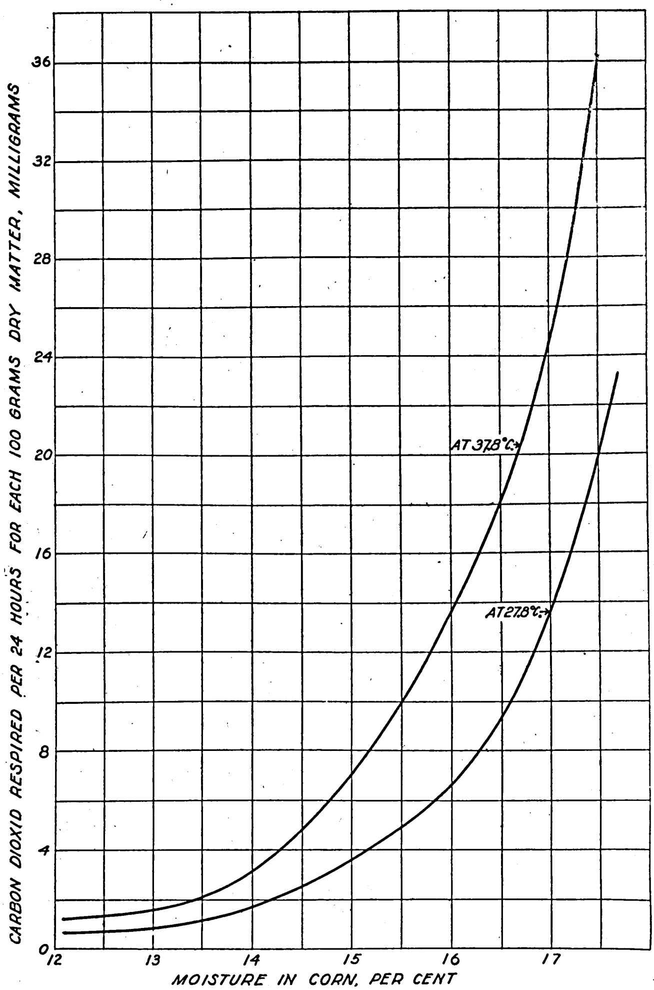

Figure 12. Rates of Respiration of Corn at 27.8° C. and 37.8° C.

CONCLUSIONS

During the curing of husked ear corn the percentage of moisture is appreciably higher in the cob than in the grain during the early stages, but the cob loses moisture at a more rapid rate than the kernels, and as the cob approaches dryness (9 per cent of moisture) the kernels contain more moisture than the cob.

Hygroscopic moisture in shelled corn in equilibrium with atmospheres of different relative humidity at 25° C. varies in different samples of corn. Sweet corn which was used contained a lower percentage of hygroscopic moisture throughout the entire range of humidity studied, and varied from about 7.8 per cent moisture at 35 per cent relative humidity to about 16.5 per cent moisture at 85 per cent relative humidity. White dent corn contained about 8.7 per cent moisture at 35 per cent relative humidity, and about 17.8 per cent moisture at 85 per cent relative humidity, or about one per cent of moisture more than sweet corn throughout the entire range of humidities studied. A sample of white dent corn of the 1919 crop was approximately intermediate between the sweet corn and the dent corn of the 1920 crop.

Distribution of moisture between the germ and the degerminated residue of the corn kernel varied with the moisture content. At higher percentages of moisture the germ contains more moisture than the endosperm, the ratio at maximum imbibition being about 1.5 to 1. At about 18 per cent of moisture both structures contain the same percentage, while as the moisture content of the kernel is further reduced the germ contains less moisture than the residue.

Moisture content in large measure determines the rate of respiration of sound corn stored under uniform temperature and other conditions, as evidenced by the data secured from the study of representative corn varieties grown from Texas to North Dakota. Northern grown corn respired somewhat more vigorously than southern grown corn. Acceleration of respiration with increasing moisture content becomes marked when the moisture exceeds 13 per cent, and increases about 400 per cent between 15 and 17 per cent of moisture. This acceleration is possibly attributable to the altered relation of water to colloidal substances which accompanies the reduction of viscosity of the complex colloidal system in the cellular material. A diminished viscosity within the limits studied in turn apparently accompanies an increased rate of diffusion of dissolved solids and gases in the respiring cells. This is indicated by the potentials and galvanometer deflections produced by the Zeleny electrode when the copper and zinc points of this electrode are inserted into the germs of kernels containing different percentages of moisture. The potentials, or E. M. F., of the small voltaic cells thus produced are almost a linear function of the percentage of moisture in the kernel, and vary within narrow limits. Deflections of the galvanometer produced by such cells are increased decidedly on increasing the moisture content of the corn kernel, and when plotted against percentage of moisture give a curve of an entirely different character from that resulting from similarly plotting their E. M. F. Thus, raising the moisture content from 14.5 to 17.7 per cent increased the galvanometer deflections by more than 2500 per cent. Since galvanometer deflections are a function of current, it follows that with fairly constant E. M. F.'s in these voltaic cells, their electrolytic resistance varies between wide limits. The resemblance of the curve representing galvanometer deflections, and hence the electrolytic resistance, to rate of respiration when both are plotted against moisture content, suggests that the same physical phenomena are operative in both instances, and that respiration, like electrolytic resistance, is determined by factors influencing the movement of ions and molecules in the cells.

During the curing of corn on the cob immediately after harvest, the rate of respiration is lower for a time than that of corn of the same moisture content later in the season. Possibly a form of dormancy is involved, resulting from a reduced rate of diffusion of oxygen into the respiring cells, or of carbon dioxid therefrom, or both. This condition is of significance in that the probability of heating is diminished during the period immediately after harvest when the moisture content of the grain is usually high.

Cracked and broken corn kernels respire more vigorously than sound, normal kernels, as was shown by comparing the rate of respiration of mixtures containing varying percentages of such material. A somewhat increased risk is accordingly involved in storing and transporting corn containing appreciable quantities of broken grain.

Sprouted kernels when dried until they contain percentages of moisture usual to commercial corn have a higher rate of respiration than sound, ungerminated kernels of the same variety and moisture content. Heat damaged, and sour and heating corn also respire more vigorously than sound corn containing the same percentage of moisture. It appears that conditions such as heating or germination which for a time accelerate respiration, leave the grain with a higher respiratory "tone," even after the accelerating influence is removed by cooling and drying. Such grain accordingly presents a greater hazard in commercial handling and storage than sound grain of the same moisture content.

Temperature affects the rate of respiration, an increase of ten degrees, from 27.8° to 37.8° C. nearly doubling the rate throughout the range of moisture studied. This is about the increase found in enzymic and other chemical reactions for each 10° C. increase, within the limits of temperature involved in this instance.

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LITERATURE CITED

Babcock, S. M.
1912. Metabolic water: Its production and role in vital phenomena. Wis. Agr. Exp. Sta. Res. Bul. 22, p. 87-181.

Bailey, C. H.
1917. The handling and storage of spring wheat. Jour. Amer. Soc. Agron., 9: 275-281.

———, and Gurjar, A. M.
1918. Respiration of stored wheat. Jour. Agr. Res., 12: 685-713.

———
1920. Respiration of cereal plants and grains. II. Respiration of sprouted wheat. Jour. Biol. Chem., 44: 5-7.

Bailey, E. M.
1912. Biochemical and bacteriological studies on the banana. Jour. Amer. Chem. Soc., 34: 1706-1730.

Besley, H. J., and Baston, G. H.
1914. Acidity as a factor in determining the degree of soundness of corn. U. S. Dept. of Agr. Bul. 102, 45 p.

Boerner, E. G.
1919. Factors influencing the carrying qualities of American export corn. U. S. Dept. of Agr. Bul. 764, 99 p.

Borodin, J. P.
1876. Physiologische Untersuchungen über die Atmung beblätterer Sprosse. St. Petersburg.

Burlakov, G.
1897. Ueber Athmung des Keimes des Weizens, Triticum vulgare. Abstract in Bot. Centralbl., Bd. 74, S. 323-324. 1898. Original articles in Arb. Naturf. Gesell. K. Univ. Charkow, Bd. 31, Beilage, p. I-XV. Not seen.

Cain, J. R., and Maxwell, L. C.
1919. An electrolytic resistance method for determining carbon in steel. Jour. Indus. and Engin. Chem., 11: 852.

Crocker, Wm.
1916. Mechanics of dormancy in seeds. Amer. Jour. Bot., 3: 99.

Duvel, J. W. T.
1904. The vitality and germination of seeds. U. S. Dept. of Agr. Bur. Plant Indus. Bul. 58, 96 p.

———
1909. The deterioration of corn in storage. U. S. Dept. of Agr. Bur. Plant Indus. Circ. 43, 12 p.

Duvel, J. W. T., and Duval, Laurel.
1911. The shrinkage of corn in storage. U. S. Dept. of Agr. Bur. Pl. Indus. Circ. 81, 11 p.

———

1913. The shrinkage of shelled corn while in cars in transit. U. S. Dept. of Agr. Bul. 48, 21 p.

Gore, H. C.

1911. Studies on fruit respiration. U. S. Dept. of Agr. Bur. Chem. Bul. 142, 40 p.

———

1914. Changes in composition of peel and pulp of ripening bananas. Jour. Agr. Res., **3**: 187-203.

Hales, S. H.

1727. Vegetable Staticks. London.

Hasselbring, Heinrich, and Hawkins, L. A.

1915. Respiration experiments with sweet potatoes. Jour. Agr. Res., **5**: 509-517.

Hoffman, J. F.

1918. Über die Selbsterhitzung der Getreide und andere Nahrstoffen. Dingler's Polytechn. Jour., Bd. 333, S. 63-67.

Landolt-Börnstein-Roth

1912. Physikalisch-Chemische Tabellen. Vierte Auflage. (Regnault tables on p. 426.)

Langworthy, C. F., and Milner, R. D.

1913. Some results obtained in studying ripening bananas with the respiration calorimeter. U. S. Dept. of Agr. Yearbook, 1912, p. 293-308.

Loew, Oscar

1899. Curing and fermentation of cigar leaf tobacco. U. S. Dept. of Agr., Dept. Rpt. 59, 34 p.

Lund, J. F.

1894. Note sur l'influence de la dessiccation sur la respiration des tubercules. Rev. Gen. Bot., t. 6, p. 353-355.

Karchevski

1901. (Influence of the fluctuation of temperature on the respiration of seeds and embryos of wheat). Abstract in Exp. Sta. Rec., **14**: 839. 1903. Original article in Mem. Warsaw Univ., **9**: 114. Not seen.

Kolkwitz, R.

1901. Ueber die Athmung ruhender Samen. Ber. Deut. Bot. Gesell., Bd. 19, Heft 4, S. 285-287.

Maige, A., and Nicolas, G.

1910. Recherches sur l'influence des solutions sucrees de divers degrés de concentration sur la respiration, la turgescence et la croissance de la cellule. Ann Sci. Nat. Bot., s. 9, t. 12, p. 315-368.

Nabokich, A. J.

1903. Über den einfluss der sterilization der Samen auf die Atmung. Ber. Deut. Bot. Gesell., Bd. 21, Heft 5, S. 279-291.

Office of Grain Standardization

1913. A series of diagrams which show graphically the monthly averages and the variation of the more important factors which are taken into consideration in the grading of commercial corn. Published by U. S. Dept. of Agr. Bur. Pl. Indus.

Osterhout, W. J. V.

1917. The role of the nucleus in oxidation. Science, N.S., **46**: 367-369.

Palladin, V. I.

1918. Plant physiology. Translated by B. E. Livingston. Philadelphia 320 pp.

Patten, H. E.
1907. Energy changes accompanying absorption. Trans. Amer. Electrochem. Soc., 11: 387-407.

Qvam, Olaf
1906. Kornets aanding, en relation mellem spireevne og. aandingsintensitet. Tidsskr. Norske Landbr., Aarg. 13, p. 263-284.

Rahn, Otto
1910. The usefulness of curves in the interpretation of microbial and biochemical processes. Mich. Agr. Exp. Sta. Tech. Bul. 5, p. 347-372.

Reed, H.. S., and Holland, R. H.
1919. The growth rate of an annual plant Helianthus. Proc. Nat. Acad. Sci., 5: 135-144.

Rodewald, H.
1895. Über die Quellung der Stärke. Landw. Versuchs Stat., Bd. 45, S. 201-227.

Sachs, J. von
1882. Vorlesungen über Pflanzenphysiologie. 5th ed. Bd. 1, p. 265. Leipzig.

Shanahan, John D., Leighty, Clyde E., and Boerner, Emil G.
1910. American export corn (maize) in Europe. U. S. Dept. of Agr. Bur. Plant Indus. Circ. 55, 42 p.

Shull, C. A.
1913. Semipermeability of seed coats. Bot. Gaz., 56: 165-199.

Suchsland, Emil
1891. Ueber Tabaksfermentation. Ber. Deut. Bot. Gesell., Bd. 9, Heft 1, S. 79-81.

Truog, Emil
1915. Methods for the determination of carbon dioxide and a new form of absorption tower adapted to the titrimetric method. Jour. Indus. and Engin. Chem., 7: 1045-1049.

White, Jean
1909. The ferments and latent life of resting seeds. Proc. Roy. Soc. (London), s. B, No. 550, 81: 417-442.

Zeleny, Anthony
1909. An electrical method for the measurement of the amount of moisture in grain and other materials. Minn. Engineer, 17: 163-170.

APPENDIX

TABLE XVII

Rate of Respiration of Minnesota No. 13 Corn, from University Farm, St. Paul Minn., Lab. No. 6854

Moisture Per cent	Carbon dioxid respired per 24 hours for each 100 grams of dry matter Milligrams
10.48	0.64
11.63	1.10
12.52	1.63
13.37	3.04
14.19	4.38
15.17	8.40
16.26	18.20
17.09	39.67
18.01	80.30

TABLE XVIII

Rate of Respiration of White Flint Corn, from Fargo, No. Dak., Lab. No. 6855

Moisture Per cent	Carbon dioxid respired per 24 hours for each 100 grams of dry matter Milligrams
10.42	0.73
11.11	0.85
12.87	1.25
13.88	2.01
14.53	3.68
15.35	7.51
15.96	12.25
16.42	19.33
17.03	39.10
18.09	82.70

TABLE XIX

Rate of Respiration of Tuxpan Corn, from Dallas, Texas, Lab. No. 6858

Moisture Per cent	Carbon dioxid respired per 24 hours for each 100 grams of dry matter Milligrams
11.53	0.82
12.62	1.34
13.49	2.17
14.38	3.46
15.28	7.56
16.19	14.52
16.85	24.25
17.22	29.67
17.94	55.12

TABLE XX

RATE OF RESPIRATION OF REID'S YELLOW DENT CORN, FROM AMES, IOWA, LAB. No. 6859

Moisture Per cent	Carbon dioxid respired per 24 hours for each 100 grams of dry matter Milligrams
10.24	0.55
11.62	1.03
12.97	2.14
14.04	3.51
15.26	5.37
16.30	10.52
16.64	13.75
17.16	18.86
17.46	25.94
18.05	44.67

TABLE XXI

RATE OF RESPIRATION OF COMMERCIAL WHITE CORN, FROM COLUMBIA, MO., LAB. No. 6860

Moisture Per cent	Carbon dioxid respired per 24 hours for each 100 grams of dry matter Milligrams
10.67	0.77
11.56	1.18
12.45	1.96
13.51	3.20
14.56	5.00
15.37	7.58
16.16	12.01
17.36	31.08
18.11	55.20

TABLE XXII

RATE OF RESPIRATION OF MEXICAN JUNE CORN, FROM PHOENIX, ARIZ., LAB. No. 6861

Moisture Per cent	Carbon dioxid respired per 24 hours for each 100 grams of dry matter Milligrams
10.73	0.58
11.47	0.82
12.33	0.90
13.45	1.93
14.52	4.25
15.40	9.01
15.93	11.98
16.52	16.41
17.36	28.87
18.14	54.78

TABLE XXIII

RATE OF RESPIRATION OF REID'S YELLOW DENT CORN, FROM COLUMBIA, MO., LAB. No. 6862

Moisture Per cent	Carbon dioxid respired per 24 hours for each 100 grams of dry matter Milligrams
11.68	1.37
13.41	2.20
14.64	3.53
15.57	7.60
16.06	10.24
17.19	20.54
18.17	49.92